A High Precision Measurement of the Deuteron Spin-Structure Function Ratio g_1/F_1

PAC 31, January 2007

- **Motivation**
- **Proposed Experiment**
- **Expeced Results**

Spin Structure of the Nucleon

- **Spin sum rule: total spin 1/2 formed by quarks (small), gluons, and orbital angular momentum (sum of these must be big).**

- **How much carried by gluons?: major focus of large experimental program worldwide (HERMES, RHIC-Spin, COMPASS, JLab, …).**

- **Jlab is contributing to this program already: one of DOE milestone for JLab is precision measurement of spin structure to Q^2=4 GeV^2**

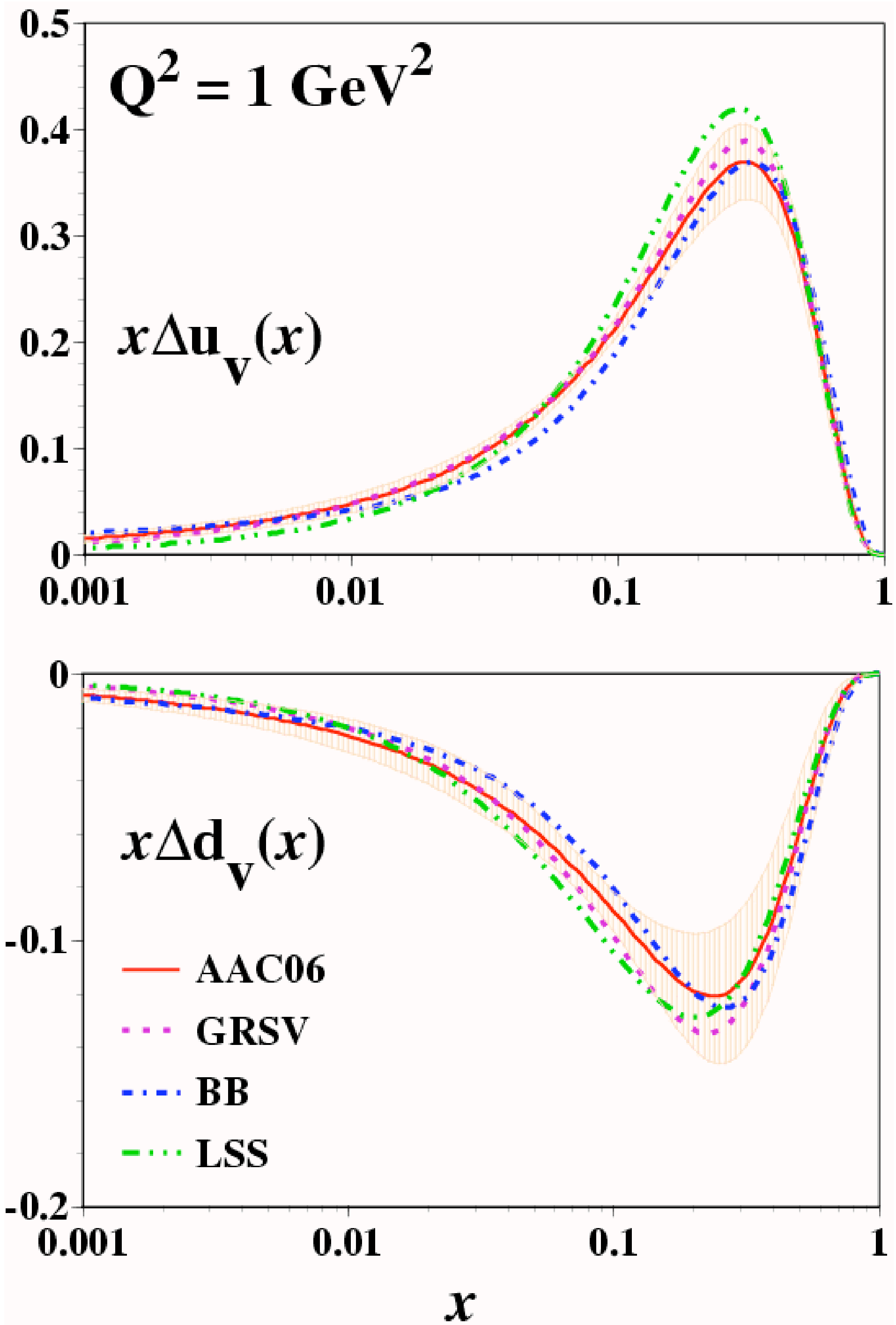
Polarized DIS

➢ **As for un polarized case, theoretically cleanest was to learn about polarized gluons is through pQCD evolution in deep inelastic scattering (DIS)**

➢**Q^2-dependence at fixed x determined by gluon radiation [log(Q^2)]. Wilson coefficients calculated to NLO in pQCD.**

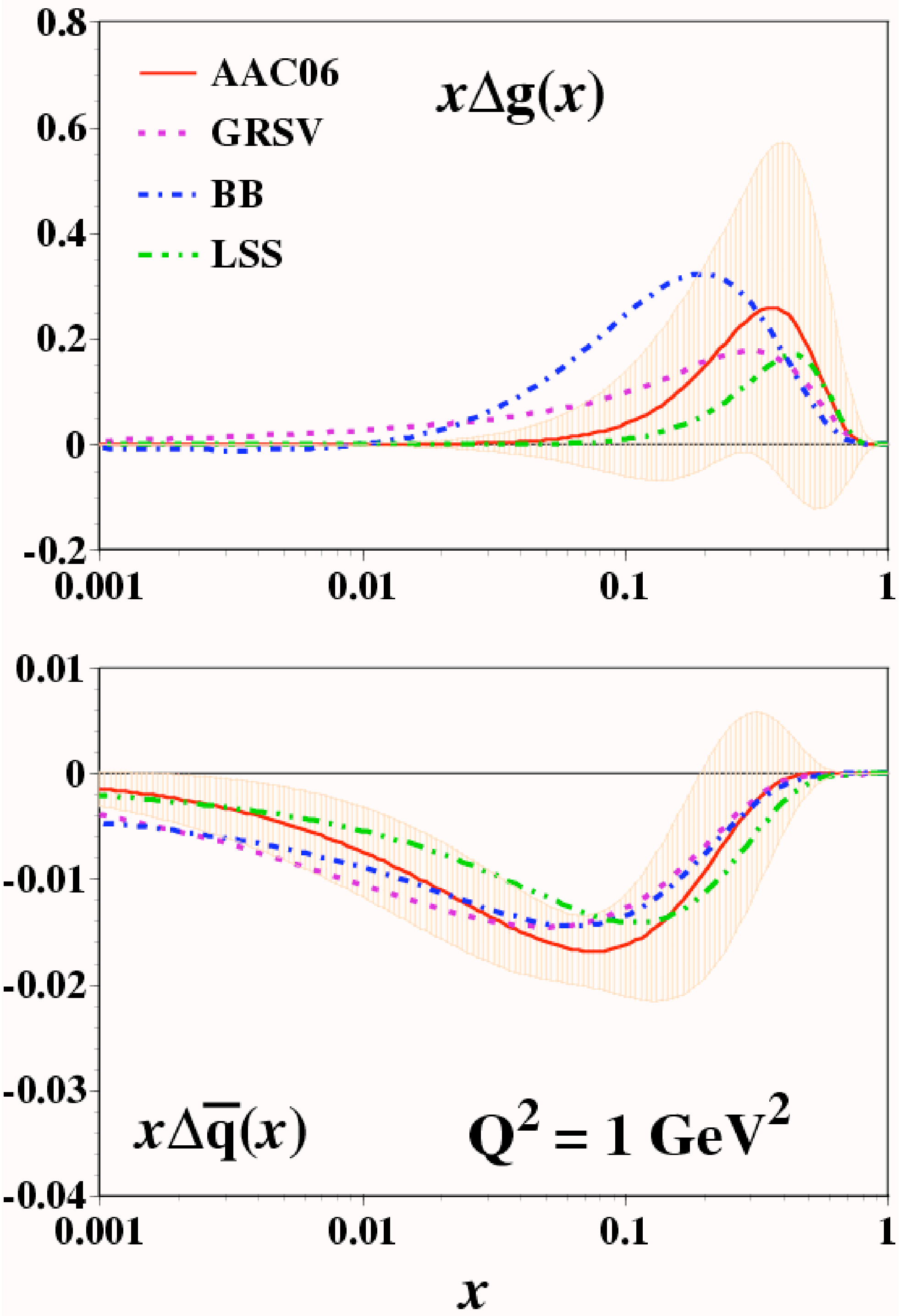
$$g_1(x,Q^2)_{\text{pQCD}} = \frac{1}{2}\sum e_q^2 \left[(\Delta q + \Delta\bar{q}) \otimes \left(1 + \frac{\alpha_s(Q^2)}{2\pi}\delta C_q\right) + \frac{\alpha_s(Q^2)}{2\pi}\Delta G \otimes \frac{\delta C_G}{N_f} \right]$$

➢**Complication: non-perturbative higher twist contributions contribute at low Q^2 (power law behavior).**



Valence Quarks

- **Pretty well known now, primarily from measurements of proton and neutron g_1**
- **Will learn more from SIDIS in future.**



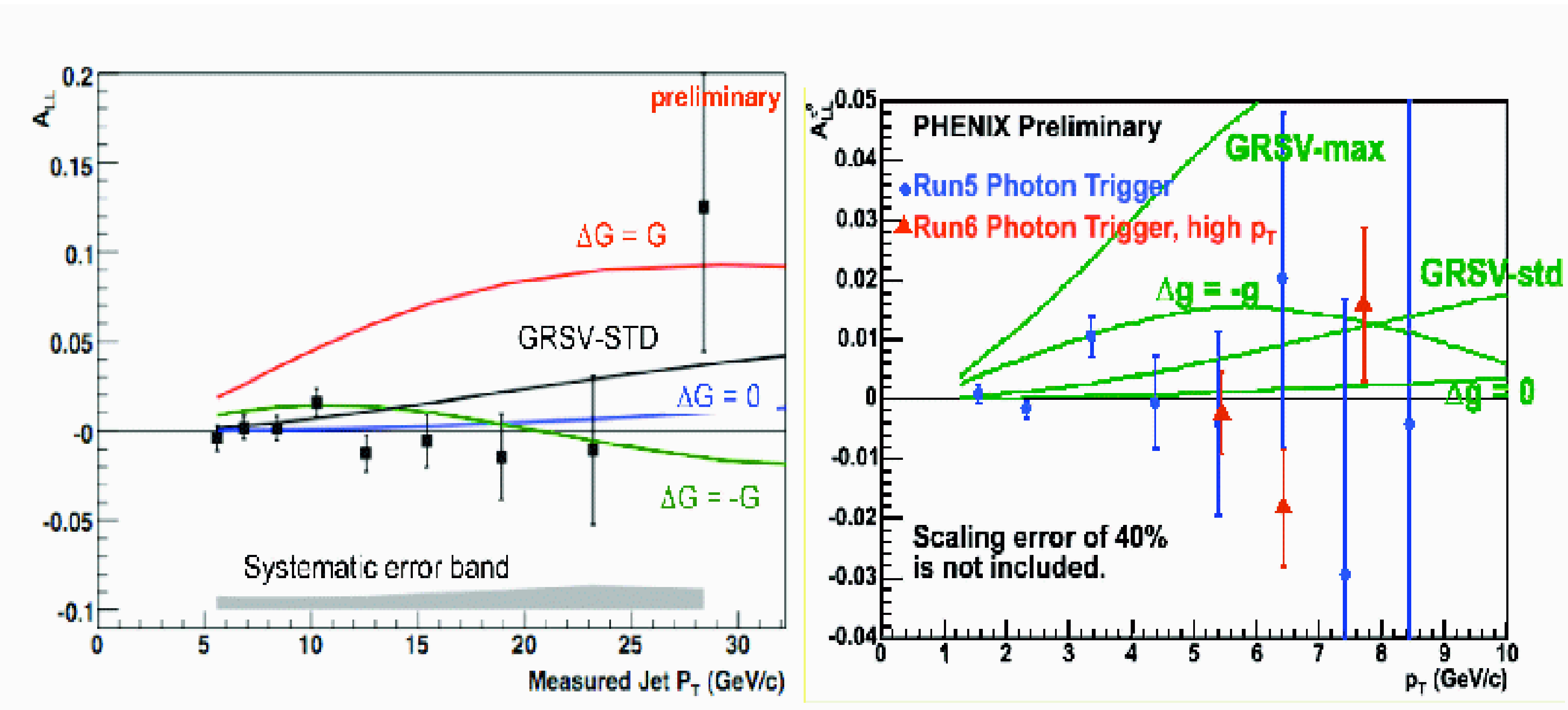
Gluons and Sea Quarks

- Gluon polarization poorly known (just that not maximal, probably positive). Need more precise data! Main goal of this experiment.

- Sea quark knowledge will improve with SIDIS Studies in future.

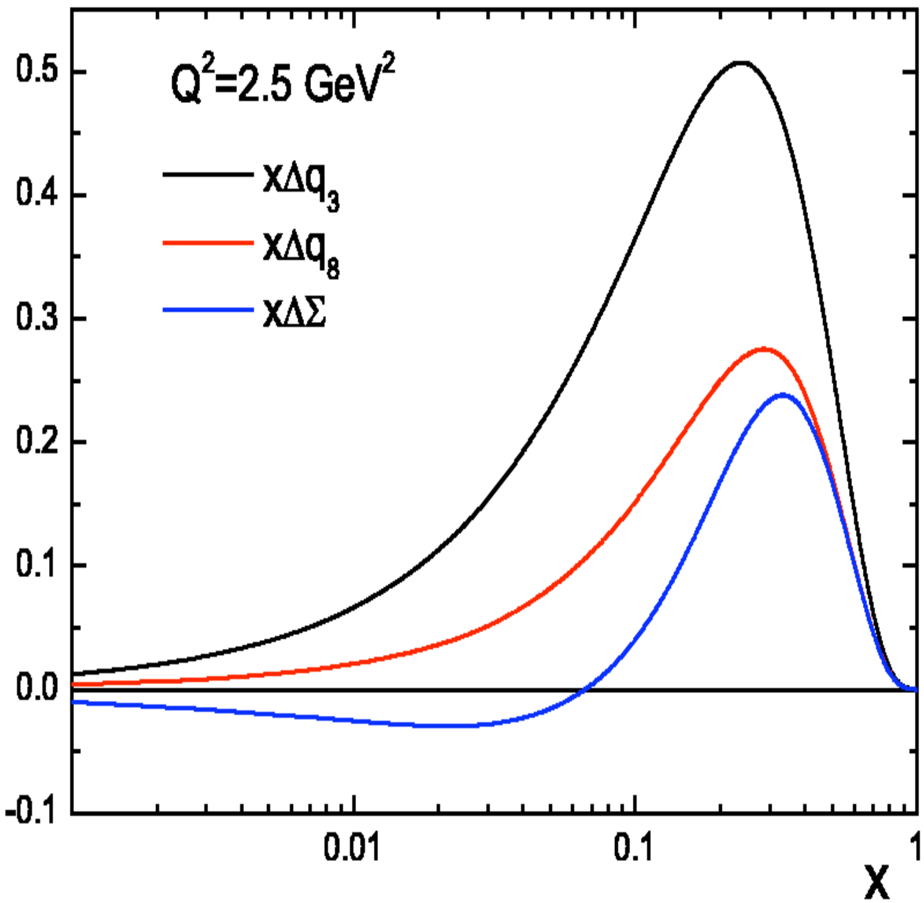
Complementary to RHIC-SPIN

- Measurements such as π^0 from STAR (left) and PHENIX (right) as a function of pt probe x<0.1.
- This proposal sensitive to x>0.1.
- Results so far rule out $\Delta G=G$.



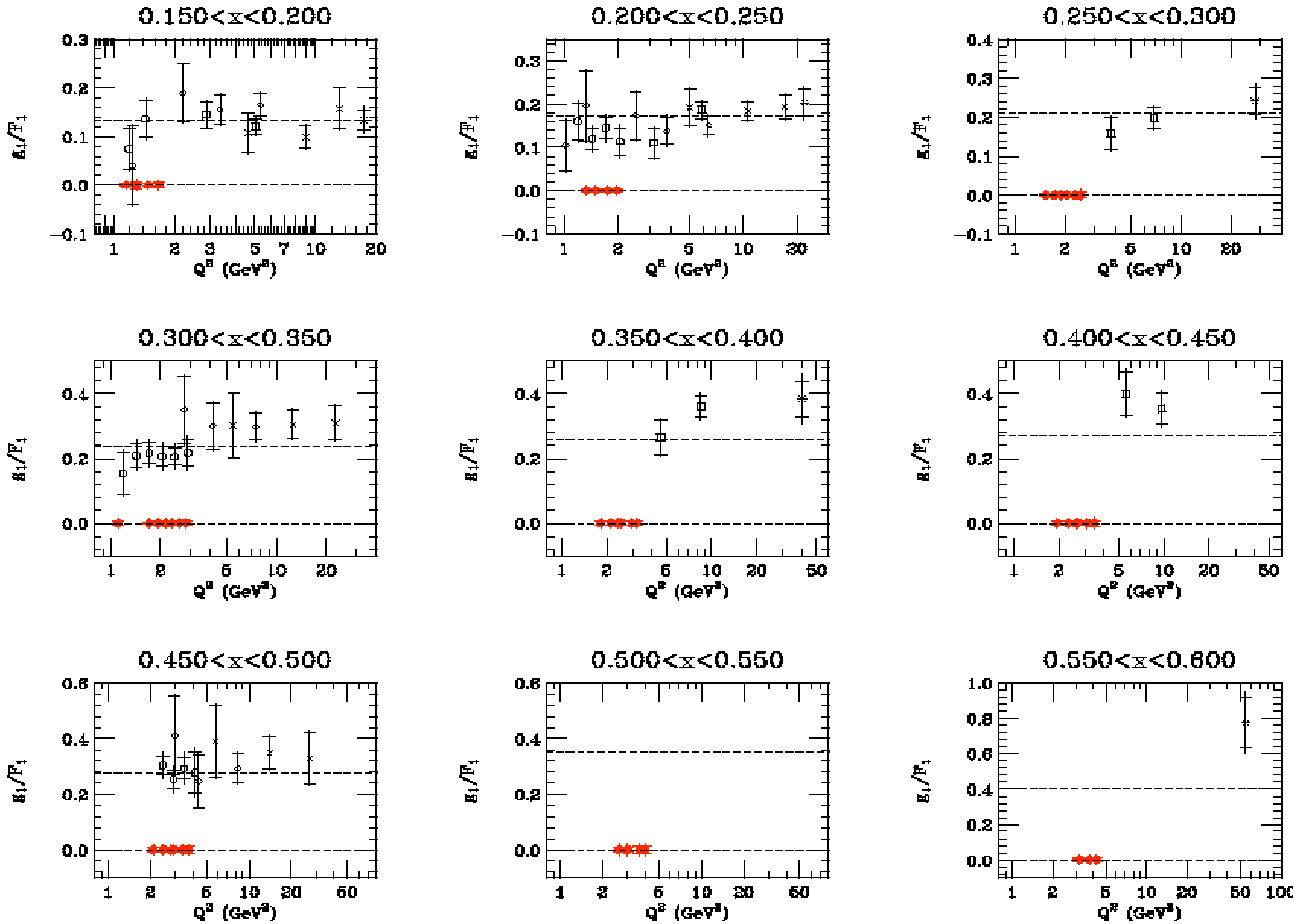
Why deuteron best for $\delta G(x)$?

$$g_1^{p(n)}(x,Q^2) = \frac{1}{9}[(\pm\frac{3}{4}\Delta q_3 + \frac{1}{4}\Delta q_8 + \Delta\Sigma)\otimes(1+\frac{\alpha_s(Q^2)}{2\pi}\delta C_q) + \frac{\alpha_s(Q^2)}{2\pi}\Delta G\otimes\delta C_G]$$

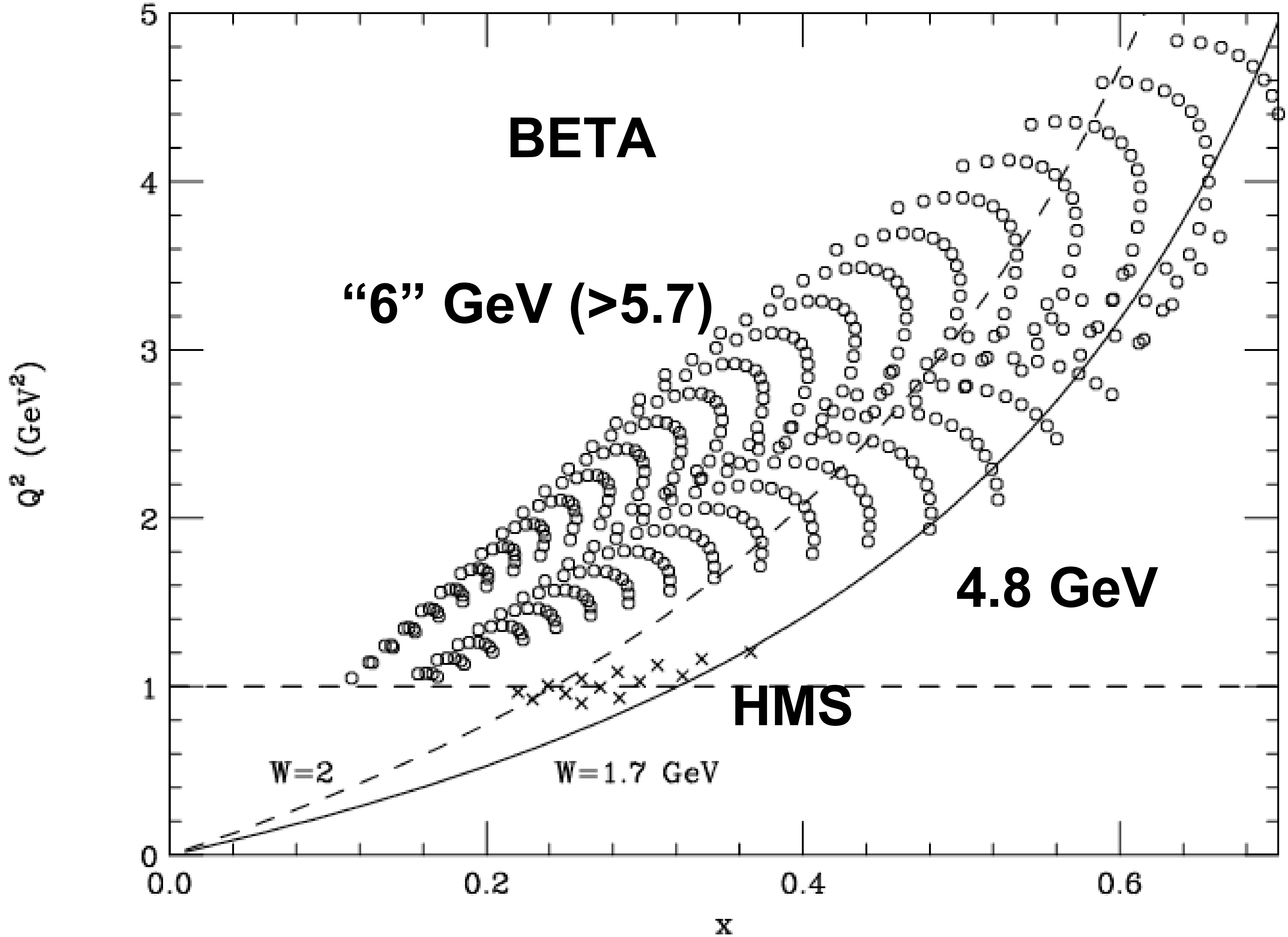


- **The $3q_3$ term cancels in deuteron, and q_3 about twice magnitude of q_8 and $\Delta\Sigma$**
- **Relative gluon contributions largest in deuteron: relevant because experimental errors dominated by systematic scale factors.**

Existing and proposed data



Kinematic Coverage



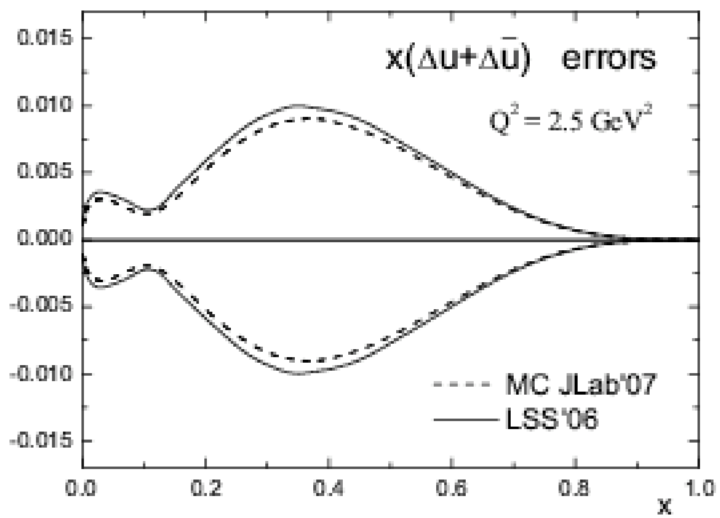
Physics Impact

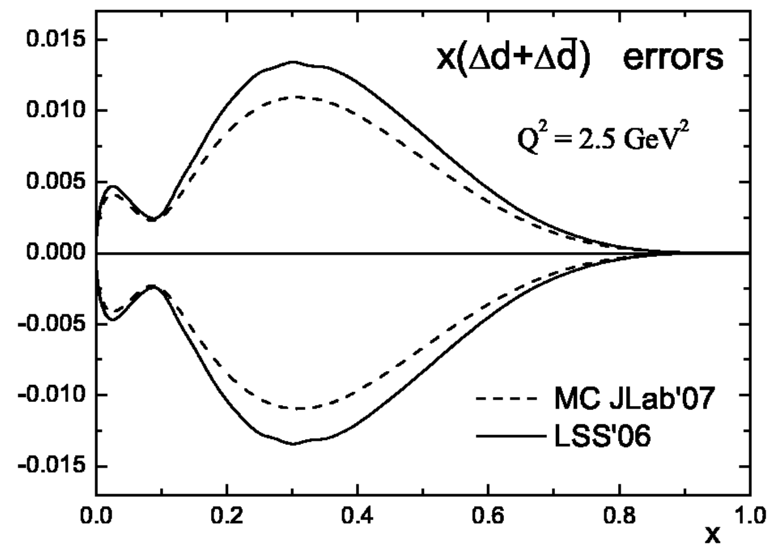
- Generated “fake” data points of this proposal following simple model.

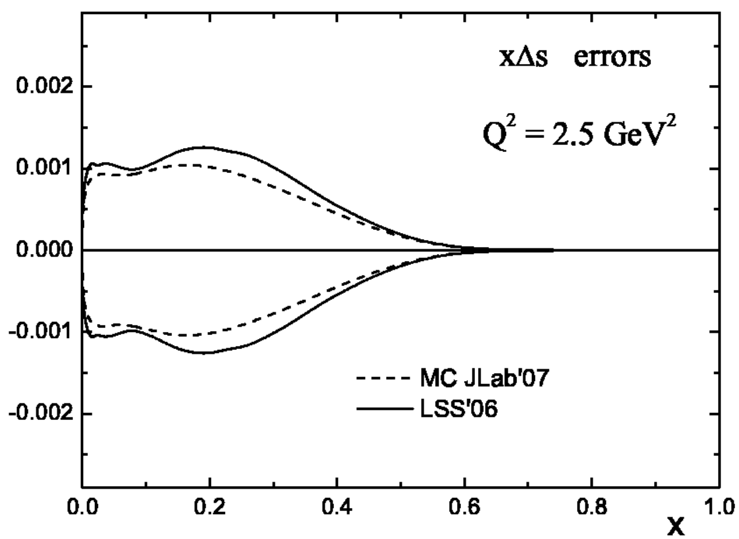
- Sent to LSS group to include in fit to world data using NLO pQCD plus phenomenological Higher Twist (HT). This group has found recent Jlab data already has significant impact.

- Also sent to AAC group to include in their NLO pQCD analysis of world data

Physics Impact in LSS framework

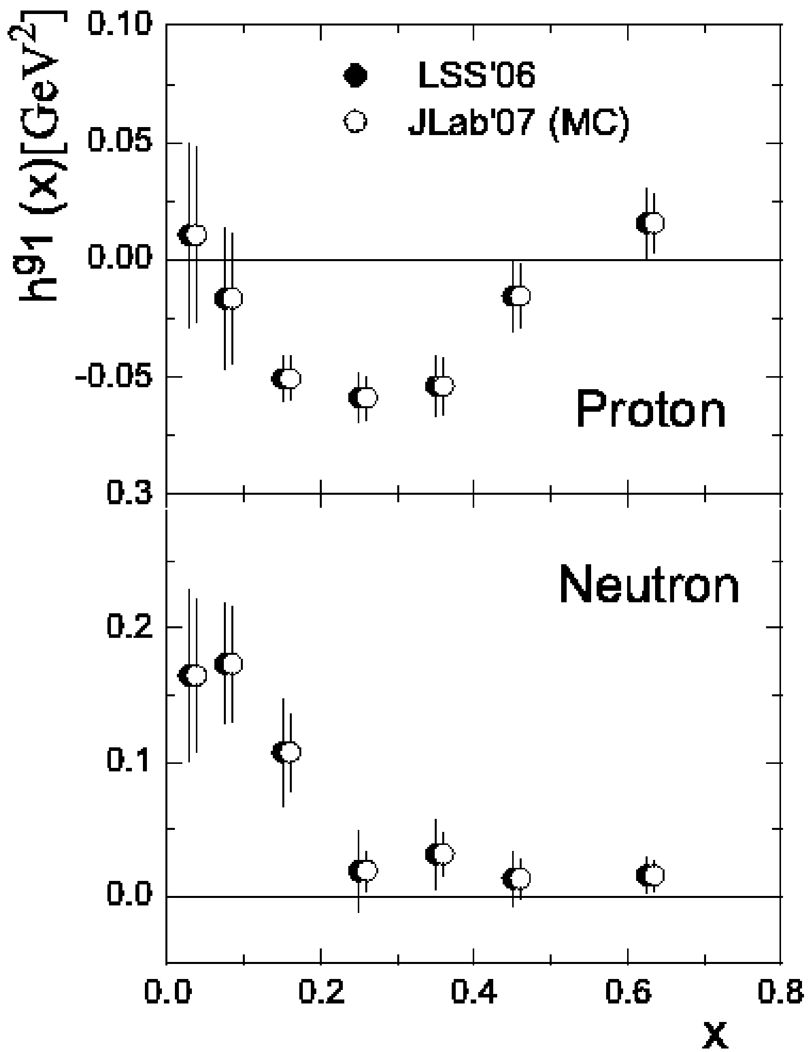


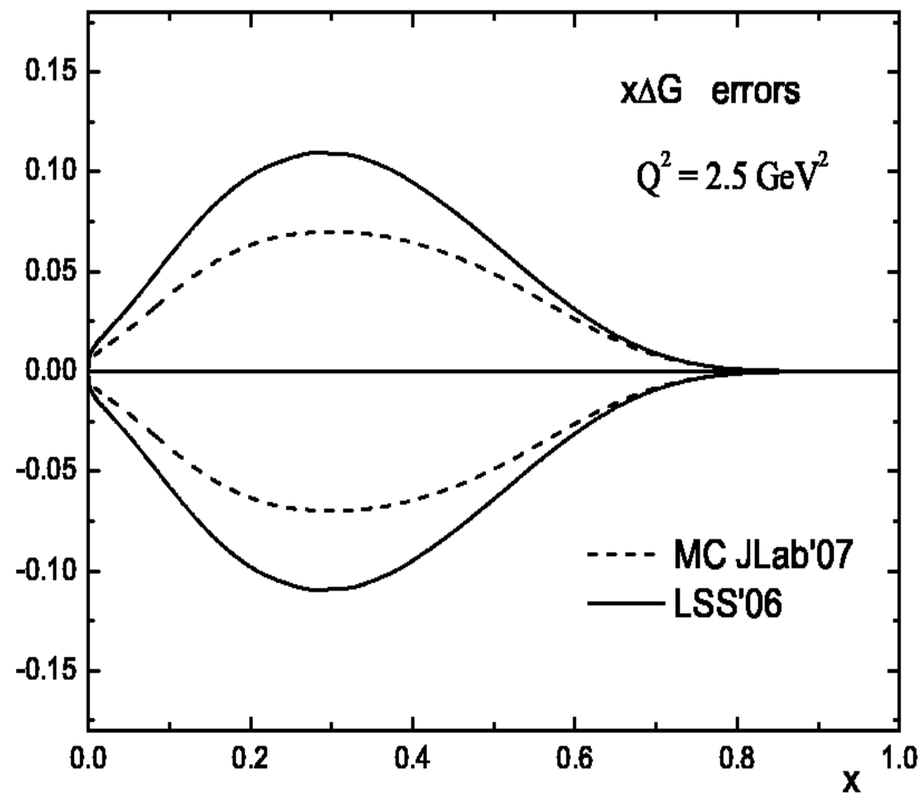




Impact on polarized quark distributions relatively small

Physics Impact





Significant improvement in $\Delta G(x)$ and neutron HT

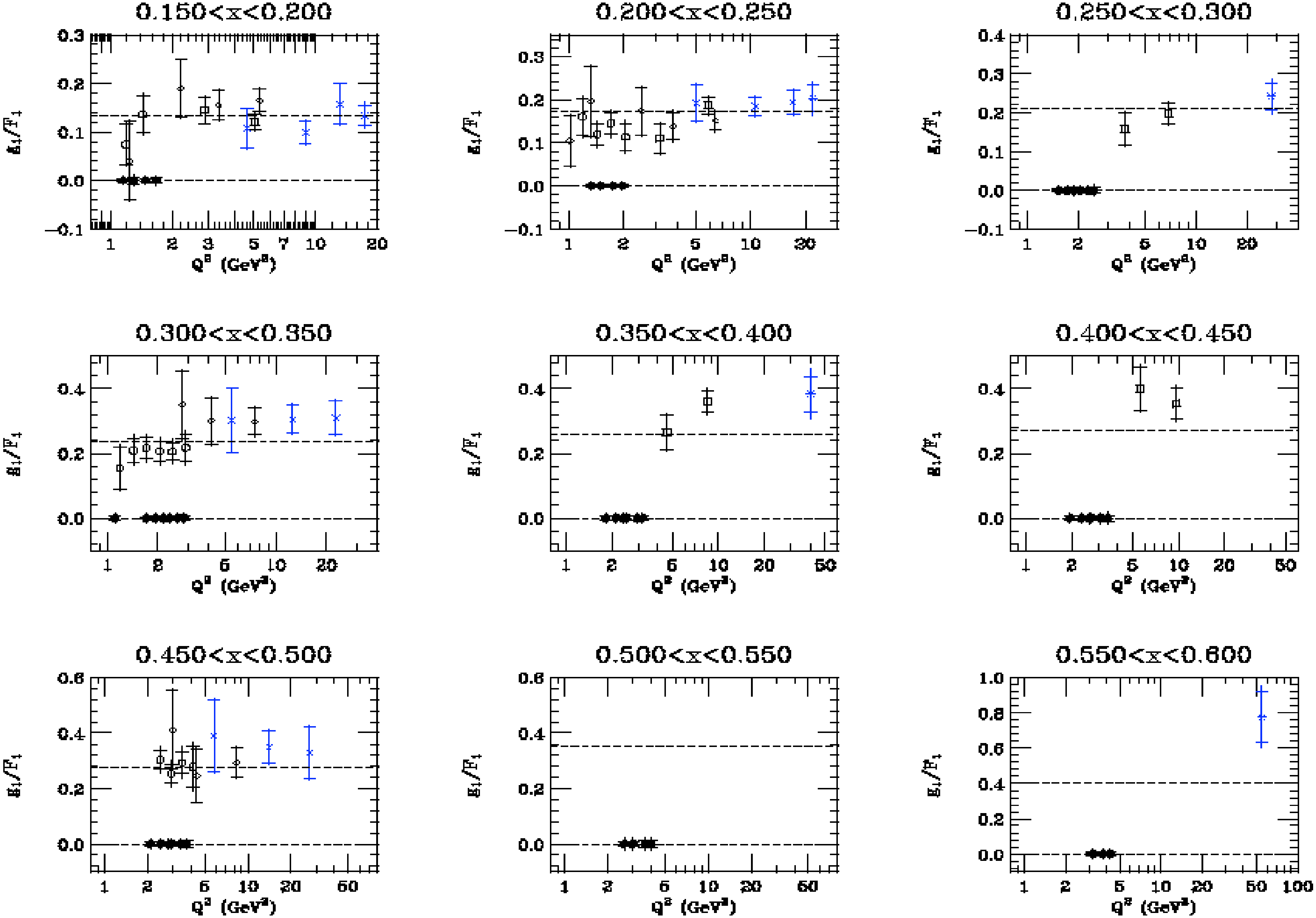
^{6}Li as Polarized Deuteron

- Most high Q^2 experiments used (SLAC) or are using (COMPASS) ^{6}LiD as target (blue points on next slide).

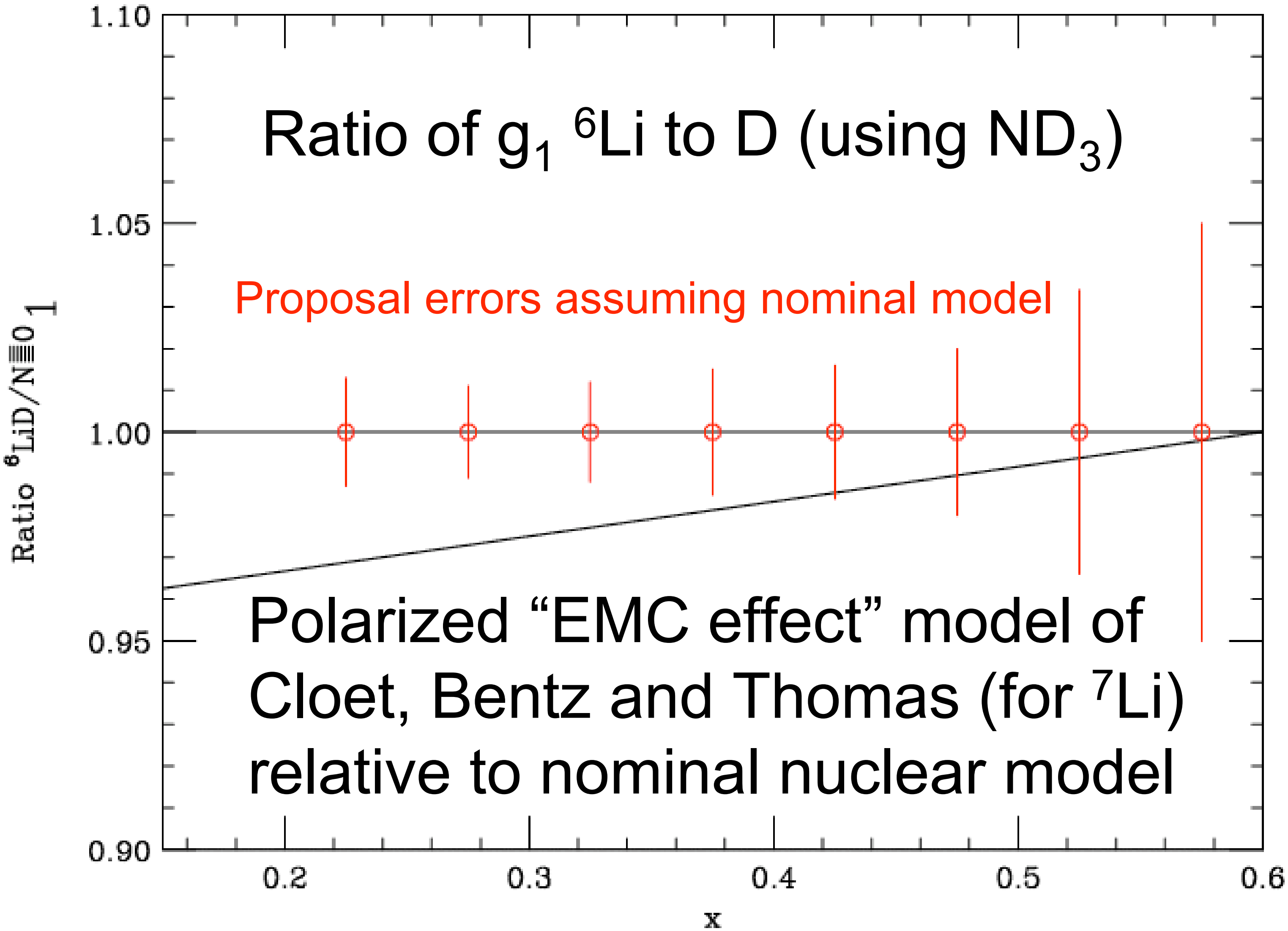
- ^{6}Li treated as unpolarized alpha particle plus deuteron with polarization 87% that of the free proton (ratio magnetic moments)

- If this assumption wrong, will bias Q^2 dependence of g_{1d} and hence extracted gluon polarization. Global problem we can solve.

Existing and proposed data



Nuclear effects in ^{6}Li



Experimental Setup

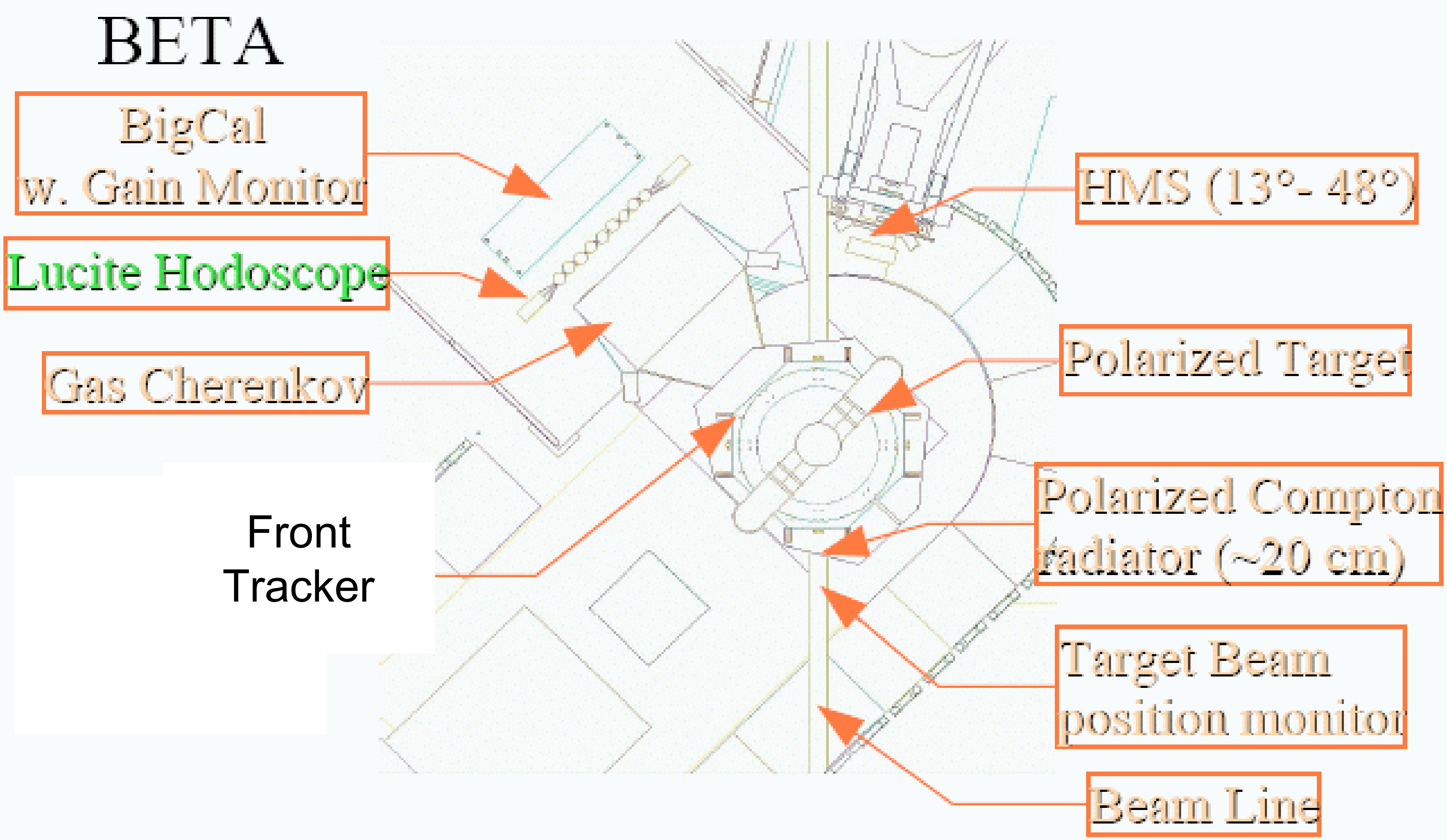
- Longitudinally polarized beam 4-pass and 5-pass (>5.7 GeV), 100 nA

- Uva/Jlab/SLAC Polarized target setup with longitudinally polarized ND_3 and ^6LiD

- Inclusive electrons detected in BETA centered at 30 degrees (and HMS)

- Identical to approved Semi-SANE experiment except for trigger (single-arm instead of coincidence).

Experimental Setup



Systematic Errors

source	p-t-p	overall
$P_b\ P_t$	-	2.8%
dilution	1%	1.5%
pair-symmetric contribution	2%	-
pion contamination	2%	-
radiative corrections	1%	1.5%
^{7}LiD and ^{6}LiH	1%	2%
pile-up, dead time	1%	1%
Total		4.1%

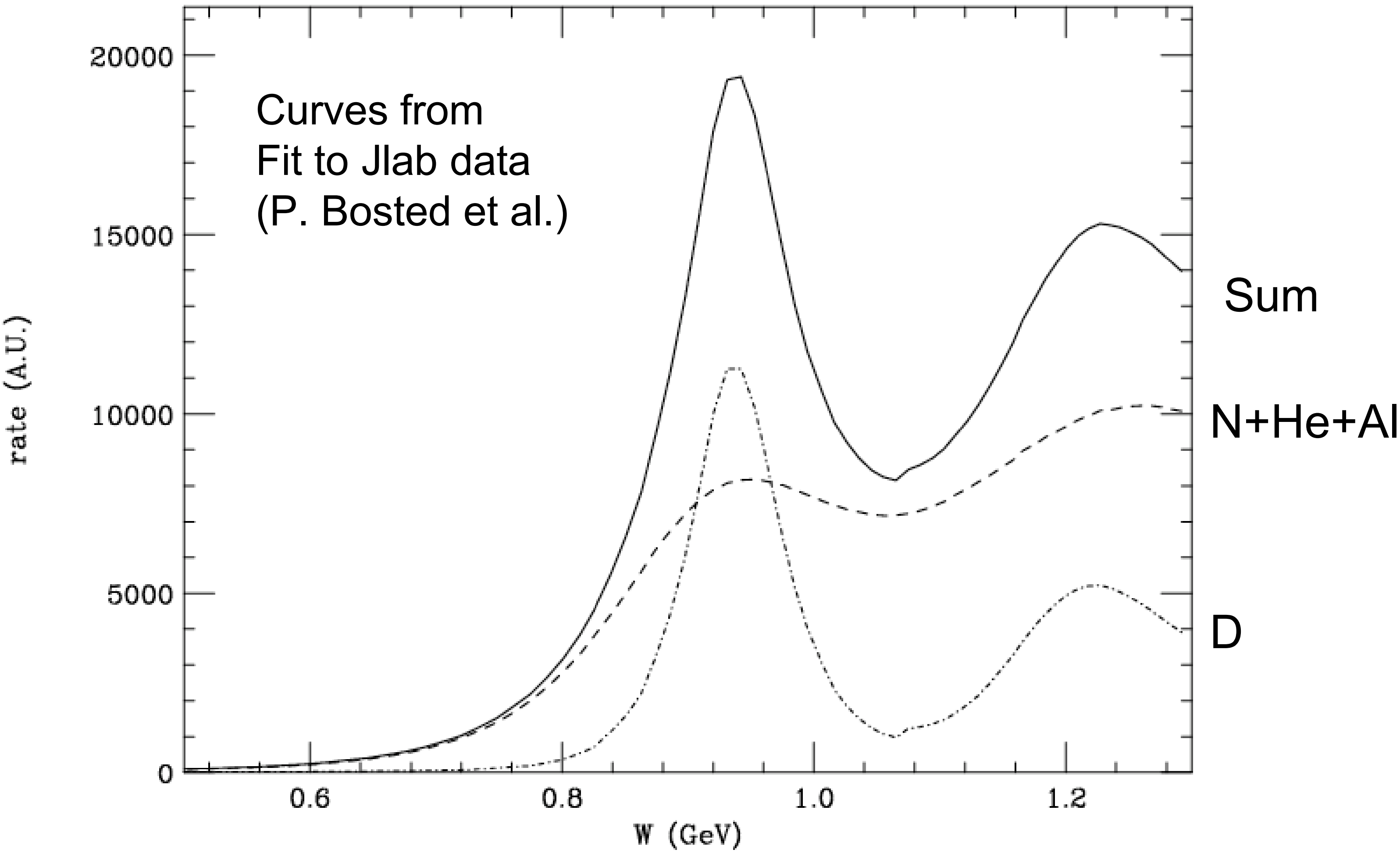
Quasi-elastic Measurements

- At low Q^2, deuteron quasi-elastic peak clearly visible in HMS spectrometer (see next slide).

- Use absolute cross sections to measure D content of the ND_3 target . Cross check of ratio of ND_3 to C rates in BETA and HMS.

- Use double-spin asymmetry to obtain product beam and target polarization (compare with full calculation of Arenhoevel including MEC and FSI). Cross check with beam Moller and target NMR.

Quasi-elastic Measurements



Request

E (GeV)	target	θ_{BETA}	θ_{HMS}	P_{HMS}	days
6.	ND_3	30.	10.8	± 2.71	8
6.	^6LiD	30.	10.8	± 2.71	6
4.8	ND_3	30.	12.	-4.3	2
4.8	ND_3	30.	16.	-2.8	3

- 19 days production (12 shared with Semi-SANE, 7 new)
- 5 days overhead (1 new)
- DAQ upgrade to 5 kHz

Collaboration

- 79 collaborators from 22 institutions.
- Strong overlap with SANE, Semi-SANE, polarized Compton experiments
- Expertise in BigCal, BETA, HMS, polarized target, polarimetry, data analysis.
- Two young enthusiastic spokespersons (one did thesis on g_{1d}) that can carry polarized target physics into 12 GeV era.
- THANKS to D. Stamenov and A Siderov of LSS group for theory support

Summary

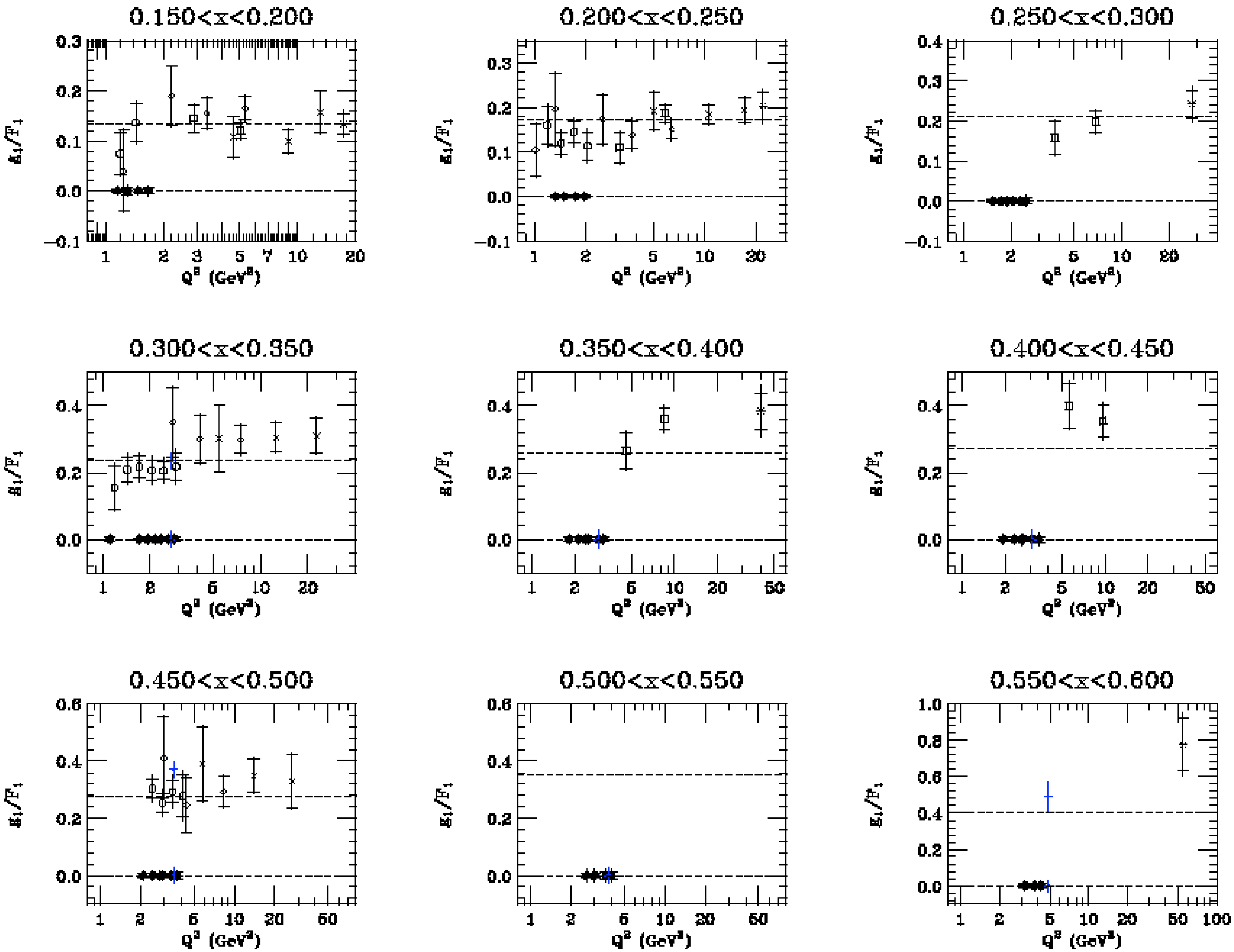
- Definitive measurements of g_{1d} in DIS range accessible at Jlab.
- Significant improvement in knowledge of polarized gluons distributions
- Improved measurements of Higher Twist
- Test of ^{6}Li as polarized deuteron: important for interpretation of high Q^2 data from SLAC and COMPASS.
- Relatively inexpensive and low impact experiment if done in conjunction with SANE and/or Semi-SANE

Backup Slides

Proton plus neutron as "deuteron"

- Alternative to deuteron target to obtain isoscaler combination is to add free proton plus neutron extracted from ^3He
- Due to scale factor systematic errors, resulting errors larger than for an actual deuteron target.
- Projected errors from SANE plus Hall A d_2 experiment shown on next slide (blue). Existing Hall B plus A data also shown.
- On other hand, allows test of ^3He as polarized neutron target

Proton plus neutron as “deuteron”



Pion, e+, radiative corrections

$<x>$	$< Q^2 >$	Pair symm.	π/e	f_{RC}	A_{RC}
0.175	1.4	15%	10%	0.90	-0.024
0.25	1.9	10%	8%	0.95	-0.019
0.35	2.5	6%	4%	0.97	-0.016
0.45	3.0	2%	1%	0.98	-0.012
0.55	3.7	1%	$< 1\%$	0.99	-0.007

Sensitivity of g_1^d to the gluon polarization

D. Stamenov

In QCD, the NLO pQCD (leading twist) contribution to the nucleon spin structure function g_1 is usually written in the following way:

$$g_1(x,Q^2)_{\rm pQCD} = \frac{1}{2}\sum_q^{N_f} e_q^2[(\Delta q + \Delta\bar{q}) \oslash (1 + \frac{\alpha_s(Q^2)}{2\pi}\delta C_q) + \frac{\alpha_s(Q^2)}{2\pi}\Delta G \oslash \frac{\delta C_G}{N_f}], \quad (1)$$

where $\Delta q(x,Q^2), \Delta\bar{q}(x,Q^2)$ and $\Delta G(x,Q^2)$ are quark, anti-quark and gluon polarized densities in the proton, which evolve in Q^2 according to the spin-dependent NLO DGLAP equations. $\delta C(x)_{q,G}$ are the NLO spin-dependent Wilson coefficient functions and the symbol $\oslash$ denotes the usual convolution in Bjorken x space. $\mathrm{N_f}$ is the number of active flavors (in the present analyses $\mathrm{N_f} = 3$).

In order to understand better the sensitivity of g_1^d to the gluon polarization it is useful to re-write the expressions for the proton and neutron spin structure functions in terms of the non-singlets $\Delta q_3(x,Q^2)$ and $\Delta q_8(x,Q^2)$, and the singlet $\Delta\Sigma(x,Q^2)$:

$$g_1^{p(n)}(x,Q^2) = \frac{1}{9}[(\pm\frac{3}{4}\Delta q_3 + \frac{1}{4}\Delta q_8 + \Delta\Sigma) \oslash (1 + \frac{\alpha_s(Q^2)}{2\pi}\delta C_q) + \frac{\alpha_s(Q^2)}{2\pi}\Delta G \oslash \delta C_G] \quad (2)$$

where

$$\begin{aligned} \Delta q_3 &= (\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d}), \\ \Delta q_8 &= (\Delta + \Delta \bar{u}) + (\Delta d + \Delta \bar{d}) - 2(\Delta s + \Delta \bar{s}), \\ \Delta \Sigma &= (\Delta u + \Delta \bar{u}) + (\Delta d + \Delta \bar{d}) + (\Delta s + \Delta \bar{s}). \end{aligned} \qquad (3)$$

As a result, the non-singlet $\Delta q_3(x, Q^2)$ term disappears from g_1^d

$$g_1^d(x, Q^2) = \frac{1}{9}[(\frac{1}{4}\Delta q_8 + \Delta\Sigma) \otimes (1 + \frac{\alpha_s(Q^2)}{2\pi}\delta C_q) + \frac{\alpha_s(Q^2)}{2\pi}\Delta G \otimes \delta C_G](1 - 1.5\omega_d). \quad (4)$$

Note that the non-singlet $\Delta q_3(x, Q^2)$ is approximately twice larger than $\Delta q_8(x, Q^2)$ (see Fig. 1 and Fig. 2). In addition, its contribution to $g_1^{p(n)}$ is multiplied by factor of 3. As a result, the relative contribution of the polarized gluon density to g_1^d is much larger than the corresponding one to $g_1^{p(n)}$. So, the data on g_1^d should be more helpful for the better determination of the gluon polarization.

Impact CLAS 6 GeV and planned 12 GeV